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Justification and optimization of dental panoramic tomography and lateral cephalometric radiography among Finnish children

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ACADEMIC DISSERTATION

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To my parents, husband, and children.

هرگز دل من ز علم محروم نشد
کم ماند ز اسرار که معلوم نشد
هفتاد و دو سال فکر کردم شب و روز
معلومم شد که هیچ معلوم نشد.

حکیم عمر خیام

My heart beating without Science – never!
Few mysteries remain unknown forever
Through days and nights a lifetime's thinking
Shows nothing is yet clear... or over.

Omar Khayyám (Persian poet and philosopher, 1048-1131 A.C.)

Contents

Abbreviations

ACC	Anatomical cranial collimator
ADA	American Dental Association
ALARA	As low as reasonably achievable
BSS	Basic safety standards
CBCT	Cone-beam computed tomography
CTP	Cephalographic thyroid protector
CVM	Cervical vertebral maturation
DAP	Dose area product
DNA	Deoxyribonucleic acid
DRL	Diagnostic Reference Level
DPT	Dental panoramic tomograph
EAPD	European Academy of Paediatric Dentistry
EAM	External auditory meatus
ESD	Entrance Surface Dose
FSR	Field-size reduction
GP	General Practitioner
ICRP	International Commission on Radiological Protection
JRA	Juvenile rheumatoid arthritis
LCR	Lateral cephalometric radiograph
LNT	Linear non-threshold theory
MRI	Magnetic resonance imaging
OR	Odd ratio
STUK	Radiation and Nuclear Safety Authority in Finland
TMD	Temporomandibular joint disorder
TMJ	Temporomandibular joint

List of original publications

This thesis is based on the following publications, referred to in the text by their Roman numerals.

I Pakbaznejad Esmaeili E, Ekholm M, Haukka J, Waltimo-Sirén J. Quality assessment of orthodontic radiography in children. European Journal of Orthodontics 2016; 38: 96-102.

II Pakbaznejad Esmaeili E, Ekholm M, Haukka J, Evälahti M, Waltimo-Sirén J. Are children’s dental panoramic tomographs and lateral cephalometric radiographs sufficiently optimized? European Journal of Orthodontics 2016; 38: 103-110.

III Pakbaznejad Esmaeili E, Ekholm M, Haukka J, Waltimo-Sirén J. Type and location of findings in dental panoramic tomographs in 7- to 12-year-old orthodontic patients. Acta Odontologica Scandinavica 2016; 74: 272-278.

IV Pakbaznejad Esmaeili E, Waltimo-Sirén J, Laatikainen T, Haukka J, Ekholm M. Application of segmented dental panoramic tomography among children: positive effect of continuing education in radiation protection. Dentomaxillofacial Radiology 2016; 45: 20160104.

Abstract

Orthodontic treatment is nowadays far from uncommon. Hand in hand with its increased frequency the numbers of radiographs taken for orthodontic diagnostics have risen. These examinations commonly list dental panoramic tomography and lateral cephalometric radiography. Orthodontics is often performed at young ages, in growing individuals with developing dentition. Along with its benefits it brings a burden in the form of exposure to ionising radiation. Given the fact that children are particularly sensitive to the adverse effects of ionising radiation and yet commonly subjected to orthodontic radiography, it is remarkable that implementation of good practice during children's dental extra-oral radiography has not been studied. The purpose of the present work was to fill this apparent lack of research and knowledge. More specifically, it aimed at analyzing dental panoramic tomography and lateral cephalometric radiography in a child population with respect to referral criteria and optimization process, in order to promote the radiation safety of children.

Retrospective analysis of 241 dental panoramic tomographs (DPTs) and 118 lateral cephalometric radiographs (LCRs) taken from 7- to 12-year-old children in the Oral Healthcare Department of the City of Helsinki in 2010 showed that all LCRs and the vast majority of DPTs were taken for orthodontic reasons, the quality of the referrals was inadequate for 22 to 27% of the images, the DPTs were mainly taken using an adult program and never using a segmented program, the field-size was too extended in most of the DPTs and LCRs, the number of failed and repeated radiographs was small, radiographic interpretation was lacking for 28 to 35% of the images, and cephalometric analysis for 33% of the LCRs, and the general and developmental pathologic findings were located in the area of the dentition. After an educational intervention program, prospective analysis of 3,883 DPTs taken from the same age group in 2013-2014 and divided into subgroups for different study purposes showed increased application of both segmented and child panoramic programs without a notable increase in repeated radiography.

This study revealed weaknesses in radiological practice from the first step to the last among children under orthodontic treatment or the potential for it. It became clear that there is a further need for continuing theoretical and professional education in radiation protection among the whole dental team, especially among orthodontists and practitioners involved in orthodontics. The study also showed that continuing education and training in radiation protection may lead to significant improvement in the optimization process.

1 Introduction

X-rays are high-energetic and high-penetrant invisible waves of the electromagnetic spectrum. They are also generated electrically in X-ray devices for medical purposes. X-rays are one of the types of ionising radiation that interact with biological cells, causing either reversible or irreversible damage or harmful health effects. Theoretically, any exposure to any dose of radiation causes a risk to health. Children and young individuals are especially sensitive to the harmful effects of ionising radiation, mostly because of their bodies' developmental and physiological status. Therefore, exposing children to any type of ionising radiation, despite of its low dosage, should always be carefully considered. The head and neck area, like other parts of the body, houses radiosensitive organs, and should likewise be radiographed with the use of precautions [1-3].

World-wide recommendations and guidelines on radiation protection released by International Commission on Radiological Protection (ICRP) form the basis of European guidelines on radiation protection and European Directives. The Finnish radiation legislation is also based on European Directive and Basic Safety Standards. Principles of radiation protection (principle of justification, principle of optimization, and principle of dose limitation) are included in the Finnish radiation legislation, and all radiological units have the responsibility to ensure that implementation of these principles takes place [2, 4, 5].

Radiographic patient selection criteria and application of methods to reduce the patient radiation-dose should rely on guidelines, national recommendations, and well-set organization-dependent advice. Application of these instructions for each patient individually in line with evidence-based data and accepted standards is good practice [2].

This work analyses how these criteria are fulfilled in dental panoramic tomography and lateral cephalometric radiography among 7- to 12-year-old Finnish children. These are the two most frequent radiographic examinations in this age group [6], a fact that drew the attention of the Radiation and Nuclear Safety Authority in Finland (STUK). Before the present study, there existed no evidence-based data on any justification process or optimization procedures of these odontological radiological examinations among children. This study evaluates the quality of extra-oral radiography of 7- to 12-year-olds step by step, reveals deficiencies in practice, and finds methods to overcome them.

2 Review of the literature

2.1 Radiation biology and adverse health effects of ionising radiation

Ionising radiation is capable of removing electrons from a neutral atom by transferring its energy to matter, leading to excitation or ionization of atoms and molecules. At cellular level, radiation injury occurs as a result of interaction of X-ray photons with cell components [3]. Radiation-induced injury is based on damage to the DNA molecule (double-strand break, single-strand break, and chromosome or nucleotide damage) [7]. Damage occurs either in a direct way through interaction of X-ray photons and DNA, or in an indirect way through radiolysis of water in cellular cytoplasm and formation of free radicals with high chemical activity that consequently injures the DNA molecule. If cellular repair and protective mechanisms fail, unrepaired, misrepaired, or irreversible DNA damage may lead to gene mutation, chromosomal aberration and translocation, cellular changes and malfunction, and even to cellular death [3, 7].

There are two radiobiological types of effects of radiation on a biological target in the human body: deterministic and stochastic effects. Deterministic effects are characterized by causing somatic changes leading to tissue damage, at and above a certain level of radiation-dose. The severity of damage depends on the absorbed dose. Examples of deterministic effects include skin damage, cataract, sterility, radiation sickness, and fetal death. Stochastic effects are characterized by random occurrence at both low and high doses, with a small probability at low doses. No threshold is low enough for stochastic effects, of which radiation-induced cancer and germ-line mutations are examples [1].

2.2 Dose quantities and dose units

Radiation absorbed dose (D) is a quantity that represents the amount of absorbed radiation energy per unit mass of tissue, and the SI unit is a Gray (Gy). Dose Area Product (DAP) or Air-Kerma-Area-Product is product of dose and beam area across the entire X-ray beam. It reflects an estimation of the overall radiation exposure delivered to the patient based on the characteristics of the X-ray beam [8]. Entrance Surface Dose (ESD) is the dose absorbed and measured at the skin surface [2].

Equivalent dose (H) is a quantity that takes into account the different radiobiological impacts of different types of radiation, and the SI unit is the Sievert (Sv). The effective dose (E) represents the radiation detriment to the whole body as a summation of the equivalent doses received by all specified tissues or organs multiplied by the corresponding tissue-weighting factors (W_T), and the SI unit is the Sievert (Sv). Parts of the body differ in radiosensitivity and have therefore their own tissue-weighting factors. This factor is a numerical value that represents the radiosensitivity of each tissue or organ in relation to ionising radiation [9, 10].

2.3 Radiation sensitivity of organs and tissues in the head and neck area

The radiosensitivity of different organs varies, and those organs composed of immature and non-specialized cells and those undergoing rapid cell division show a higher degree of radiosensitivity [11].

Of the tissues in the head and neck area, the thyroid gland is a very radiosensitive organ with a high carcinogenic risk during childhood [12]. Benign thyroid nodules, hypothyroidism, and autoimmune thyroiditis may also occur as a result of exposure of the thyroid gland to ionising radiation [13]. Red bone marrow, found abundantly in the head and neck skeletal system, is an organ with high carcinogenic risk and is classified as one of the most radiosensitive organs [4]. Moreover, in individuals under age 20, a relationship has been evident between ionising radiation and malignant brain tumours, mostly involving those undergoing radiotherapy [14]. Considering children's underdeveloped central nervous system, therefore, radiological examinations of the head area should be performed with caution [14]. One epidemiological study establishes a relationship between prior medical or dental radiography and brain and parotid gland cancers [15]. Eyes are not classified as potential organs for manifesting stochastic effects, but studies do show some risk for cataract development after exposure even at low doses [16].

During extra-oral radiography, both the image receptor and the source of radiation are located outside the mouth, leading to irradiation of a larger volume than in intra-oral radiography. Nevertheless, the threshold doses for occurrence of deterministic effects of radiation are definitely far greater than are doses derived from dental extra-oral radiography. The lifetime probability of and risk for fatal cancer as a result of exposure during dental extra-oral radiography is very low, but it cannot be ruled out completely [2].

In the revised recommendations of the International Commission on Radiological Protection (ICRP), new organs such as the brain, salivary glands, and oral mucosa have been included in calculation of the whole-body effective dose. This means that these organs have each been given their own tissue-weighting factors after being categorized as organs with a specific risk for stochastic effects [4]. Inclusion of these organs has led to the concept of an increased risk from radiation during dental radiography [17].

2.4 Radiation risk during childhood

Children are more susceptible to the carcinogenic potential of ionising radiation than are adults receiving the same dose. Their risk for developing leukaemia, skin, thyroid, and brain cancer, in particular, is elevated. They also suffer an increased risk for deterministic effects such as cognitive defects, cataract, and thyroid nodules, as a result of exposure to ionising radiation during childhood [2, 9, 14, 18]. One estimate is that in children radiation induces a risk that is two or three times as high as in adults. The higher radiosensitivity of children is linked to the following factors: 1) longer life expectancy that brings along a greater chance for repeated exposures and accumulated damage, and a longer time-period to develop the disease, 2) developmental and physiological status of the organs, 3) more developing and growing tissues, containing many undifferentiated cells and cells with a high rate of division and mitotic activity, 4) higher radiation-dose accumulation, and 5) smaller body size and less protection of superficial organs [2, 9, 14, 18].

Therefore, due to the potential harm, the recommendation is to avoid any unnecessary exposure even at a low dosage. The statement of the ICRP has formulated this as follows: "*The probabilistic nature of the stochastic effects makes it impossible to make a clear distinction between 'safe' and 'dangerous', a fact that causes problems in explaining the control of radiation risks*" [1]. Consequently, because of the higher probability of manifesting a stochastic effect of ionising radiation in children than in adults, it is particularly important to implement the general aspects of radiation protection in children [4, 19].

2.5 Frequency of extra-oral radiography in Finnish children

In Finland, of the 3.9 to 4.2 million X-ray examinations annually, less than 10% are taken of children [20, 21]. In 2008, of conventional radiographic examinations, about 8%, and in 2015 6.9% were performed on children aged less than 17 years [6, 21]. Of these examinations, 40% were performed on 7- to 12-year-olds in 2008 [6]. No corresponding percentage is available from 2015.

The high frequency of exposures in this age group is at least partly explained by the frequency of dental extra-oral radiography. In Finland, of all children's (< 17 years) dental panoramic tomographs (DPTs), 68%, and of all children's lateral cephalometric radiographs (LCRs), 75%, were taken of 7- to 12-year-olds. Of the total population of 7- to 12-year-olds in Finland in 2008, numbering 355,342 children, 7% were subjected to DPT and 4% to LCR [6].

DPT as the most frequent radiographic examination (23,862) comprised 27% of all the conventional radiographic examinations, and LCR as the second most frequent (14,035) comprised 16% of all the conventional radiographic examinations among 7- to 12-year-olds in 2008 in Finland. In comparison, among 2- to 6-year-olds without LCRs, DPT comprised 8% of all the conventional radiographic, and among 13- to 16-year-olds DPT comprised 13% of all the conventional radiographic examinations, and LCR comprised 6% [6].

For further comparison, wrist X-rays, thorax X-rays, arm and finger X-rays, paranasal sinus X-rays, and ankle X-rays among other examinations of the 7- to 12-year-olds comprised 11%, 9%, 9%, 7%, and 7% of all the conventional radiographic examinations, respectively. It should be noted that intra-oral dental radiographic examinations are not included in any of these statistics [6]. The large number of extra-oral radiographic examinations in 7- to 12-year-olds drew STUK's attention [6].

After the start of this study, more recent figures have emerged. Looking at the numbers of extra-oral radiographs taken of children (aged less than 17 years) in 2015, it becomes apparent that of the DPTs, 76% (19,473 out of total 25,755) and of the LCRs, 83% (11,175 out of total 13,537) were taken of 7- to 12-year-olds. Of all the conventional radiographic examinations within this age group, DPT was still found to be the most frequent type, with a proportion of 23% (19,473 of a total of 83,724), and LCR the second most frequent, with a proportion of 13% (11,175 of a total of 83,724) [21].

2.6 Radiation protection

2.6.1 International guidelines and recommendation

The ICRP is an independent and international organization that consists of volunteer members from several countries. It provides world-wide recommendations and guidelines on all aspects of radiation protection. The main goal of the ICRP is to minimize radiation-induced health effects and to contribute to environmental protection [22]. The ICRP regularly releases its own publications, *Annals of the ICRP* (http://www.icrp.org/publications.asp), on all aspects of radiological protection, based on the knowledge and science of radiation exposures and ethics. These publications, concerning the principles of radiation protection, form the basis of ICRP fundamental recommendations. The lack of any known threshold for manifestation of possible stochastic effects (carcinogenic and heredity effects) due to exposure to ionising radiation and its cumulative nature forms the baseline for the principle of radiation protection [4].

The international principles of radiation protection as defined by the ICRP:

- *"The Principle of Justification: Any decision that alters the radiation exposure situation should do more good than harm.*
- *The Principle of Optimisation of Protection: The likelihood of incurring exposure, the number of people exposed, and the magnitude of their individual doses should all be kept as low as reasonably achievable, taking into account economic and societal factors.*
- *The Principle of Application of Dose Limits: The total dose to any individual from regulated sources in planned exposure situations other than medical exposure of patients should not exceed the appropriate limits specified by the Commission"* [4].

2.6.2 European legislation and guidelines

Radiation legislation in Europe is based on ICRP recommendations. The European Directive, set by Euratom, represents Basic Safety Standards (BSS) for protection against hazardous effects of ionising radiation. All member states of the European Union, including Finland, are obligated to set their own national legislation and local regulations based on the BSS Directives under the Euratom Treaty [2].

Any radiological department engaged with ionising radiation is obligated to practice under the regulations and legislation set by its own country [2]. The requirements of radiation protection also apply to each department dealing with dental radiography, and the European guidelines on radiation protection in dental radiology are based on the same Euratom Directives. They provide comprehensive information and guidance on safe use of radiation in dentistry [2]. The European Academy of Paediatric Dentistry (EAPD) guidelines for use of radiography in children focuses on the radiographic selection criteria and methods for minimizing patient exposure with more details in children [23].

The European Commission states, *"Guidelines are not a rigid constraint on clinical practice, but a concept of good practice against which the needs of the individual patient can be considered"* [2]. Practitioners must make their decisions and judgment case-specifically. Practitioners' routine judgment does not necessarily apply to every patient, with regards to the justification process and optimization procedures [24].

2.6.3 National legislation and guidelines

The Finnish radiation legislation is based on the BSS Directives under Euratom (Council Directive 96/29/Euratom) [25]. The Ministry of Social Affairs and Health of Finland has decrees for the medical use of radiation under the Finnish legislation and radiation act (592/1991) [5]. Principles of radiation protection and their implementation have been set as absolute guidance for high-quality radiological practice in Finland [26]. The STUK, as an administrative branch of the Ministry of Social Affairs and Health, is an official regulatory control body that looks after the implementation of council directives, and ministry's decrees. The STUK supervises the safe use of radiation on the basis Finnish radiation protection legislation, safety regulations, and guidelines, in order to protect individuals from hazardous effects from ionising radiation (www.stuk.fi). The STUK's own serial publications, regulations, and brochures form the basis of the protocols and instructions for imaging in any department that requests radiographic investigations.

In Finland, local legal requirements concerning referral criteria, safe use of radiation, and optimization of procedures are given in detail in several Guides released by the STUK (ST guide) [26-28]. In addition, criteria for radiographic examinations in the paediatric population are discussed in more detail in the "Children's X-ray examination criteria", a guide released by STUK [20].

STUK has set dose limits (maximum exposure per calendar year) for exposed workers, students, and members of the public, based on the Radiation Act of Finland. Dose limits do not, however, apply to patients undergoing medical exposure because the limits might jeopardize diagnosis or reduce the effectiveness of treatment [29, 30]. For doses received by patients during medical exposures, the Ministry of Social Affairs and Health of Finland obligates operators of radiological units to apply diagnostic reference levels (DRL) as part of their optimization processes and quality assurance in line with European Medical Exposures Directives. DRLs are pre-defined radiation-dose levels of X-ray examination, expected to be exceeded in a patient of normal size in good practice [31]. DRLs provide an investigation level and a maximum acceptable level in contemporary normal radiological practice [2], but not for individual patients. The purpose of establishing DLRs is to identify sources of errors in radiological practices (either actions or equipment) that lead to an average patients' doses being above set levels. Average patient doses must be measured or calculated and consequently compared to the established national DRL at least every three years [2, 31].

DLRs have been set for the most common radiological examinations. In Finland, national dental DLRs are issued by the STUK and are summarized in Table 1.

Table 1 Established diagnostic reference levels for several intra-oral and extra-oral dental radiographic examinations in Finland [32, 33].

Projection or indication	DRL as ESD (mGy) or as DAP (mGy×cm^2)
Intra-oral (upper molar) [32]	2.5 mGy
Dental panoramic tomography [32]	120 mGy×cm^2
CBCT: preoperative implant planning (single tooth) [33]	360 mGy×cm^2
CBCT: preoperative assessment of relationship between inferior alveolar nerve and impacted mandibular third molar [33]	380 mGy×cm^2
CBCT: evaluation of periapical area and root canal morphology [33]	550 mGy×cm^2
CBCT: evaluation of paranasal sinuses (trauma) [33]	1150 mGy×cm^2

DRL, diagnostic reference level; CBCT, cone-beam computed tomography; ESD, Entrance Surface Dose; DAP, Dose Area Product.

2.6.4 Good practice

Definition of the term "good practice" has been formulated by the European Commission as follows: *"Good practice is the practice which can be recommended based on the most recent considerations of evidence based data, long term experience and knowledge gained on the necessary structure, process and outcome"* [34]. The criteria of good practice are based on national or international standards, generally accepted rules, guidelines, legal requirements and regulations, results of research, consensus statements, and recommendations of national professional societies, special committees, or auditing organizations [34].

Quality assessment of radiological practice should take place frequently [27, 28, 34-36]. It includes evaluation of the whole process occurring in a radiological unit, and it is one of the obligations of operators of radiological units to compare their local practice to the criteria of good practice. This requires either external or internal audits depending on the safety classification of the system, type of X-ray activity, and type of devices of a radiological division. Quality assessment of practice in a small unit dealing with, for example, intra-oral radiography, dental panoramic tomography, and cephalometric radiography (class I type of activity) could take place in the form of self-assessment procedures. Justification and referral practice, including referral criteria, as well as optimization procedures, are important parts of the quality of any radiological practice, and should be evaluated regularly by assessing whether or not the local practice is in line with the criteria of good practice, thus identifying areas for future improvements [28, 34, 36].

2.7 Radiographic selection criteria

2.7.1 Selection criteria in general

For medical exposure, in addition to general aspects of justified use of ionising radiation for medical purposes and safety of the imaging technique, attention should focus on the individual need of each patient [24]. A radiographic examination is a diagnostic supplementary tool for clinical examination and should be ordered when additional information that it provides will affect patient management [37]. Any radiographic examination should be carried out based on the patient's medical history, oral history, and clinical signs and symptoms [2].

According to the European Commission, before referring a patient for any radiographic examination, the following aspects are vital to carry out the justification process:
1) Does the radiographic examination provide potential new information that would aid diagnosis and would affect patient treatment?
2) Is the imaging technique the most appropriate one, or does any better alternative method involve a lower radiation-dose?
3) Are there previous radiographs that might fulfil our aim? [24].

A referral or request for a radiographic examination should be sufficiently accurate in stating the reason for radiography and the main clinical findings, aiding in radiological diagnostics [24]. The importance of mentioning the indication for radiography and other information of clinical relevance in the referral text for optimizing dental radiography is stressed in ST Guides, as well [27]. Radiographic referral criteria or selection criteria are also a legal requirement for dental radiography, and their importance is discussed in details in the guideline prepared by the European Commission [2, 38].

Both the referring practitioner and the person responsible for taking the X-ray should justify the procedure before exposure [2]. This cannot be achieved without an adequate referral and strong cooperation between the referrer and the staff of the radiological unit. Implementation of referral criteria in turn leads to reduction in the number of unnecessary exposures [24].

2.7.2 Selection criteria in orthodontic radiography

Instructions for the prescription of various radiographic views and their function in orthodontic practice are discussed in the guidelines released by the European Commission [2]. These guidelines strongly urge the application of the recommendations that concern orthodontic radiography, in order to promote the justification process of radiography in a developing dentition [2].

The recommendations for patient selection and limitation of radiation exposure during dental radiographic examination, published by the American Dental Association (ADA), are instructions for prescription of dental radiographs, based on clinical judgment, during different dental developmental stages [37]. These recommendations are, however, very brief and include only radiographic selection criteria during the transitional stage of dentition development.

Orthodontic Radiographs, published by the British Orthodontic Society, are the only guidelines available at the moment that discuss selection criteria for the use of intra-oral and extra-oral radiography in orthodontics and methods of optimization of exposure during orthodontic radiography

[39]. In these guidelines, special attention focuses on the clinical justification of DPTs and LCRs. The importance of clinical examination and study casts prior to prescription of radiographs is an essential part of the treatment plan, challenging the need for radiography. The most relevant indications for DPT are specified as clinical need to ascertain the state of the dentition and confirmation of the presence/absence, position and morphology of unerupted teeth. Similarly, the indication for LCR has been specified as the need to 1) assess the skeletal pattern and the angulation of the labial segment, 2) monitor the effect of the treatment, 3) monitor changes due to growth, and 4) locate and assess unerupted, malformed, or misplaced teeth [39].

According to the same guidelines, it is not justified to take DPT or LCR in the following situations: 1) radiography before a clinical examination, 2) of all new patients to screen out asymptomatic ones, 3) repeated DPTs at arbitrary time intervals, 4) of all patients with temporomandibular joint (TMJ) disorders (TMD), 5) a single LCR for the prediction of facial growth, 6) prospective radiographs for medico-legal reasons, 7) after treatment for professional examination or for clinical presentation, as well as 8) Cone-beam computed tomography (CBCT) of all orthodontic patients [39].

Today, the value of DPT is debated by some authors, and CBCT is presented as a superior alternative [40]; others, however, do not accept CBCT, owing to its higher radiation dose, as the imaging technique of choice for orthodontic patients and do not consider CBCT superior to DPT and LCR except for any special patient group with a strict indication [41]. The British Orthodontic Society recommends careful and cautious orthodontic application of CBCT and does not justify its routine use for all orthodontic patients [39]. Evidence-based guidelines prepared by the SEDENTEXCT project and released by the European Commission on use of CBCT in dentistry identify referral criteria and orthodontic application of CBCT during developing dentition that must receive special attention [29].

2.8 Principles of panoramic tomography and cephalometric projections and development of devices

Dental panoramic tomography is a valuable extra-oral radiographic technique that enables two-dimensional broad visualization of hard tissues located in the maxillomandibular area and adjacent bony structures. The nature of this technique is tomographic, meaning that structures located within a section of the body will appear sharply in the final radiograph [42]. The development of rotational panoramic tomography with an extra-oral source of X-rays has occurred since 1933. The first prototype for orthoradial jaw pantomography was built by a Finn, Yrjö Paatero, in 1958. This technique was applied in clinical practice in 1959. The principle of panoramic image formation is based on rotational tomography, the result of synchronized movement of an X-ray source and an image receptor around the patient’s head. Even though the final image consists of the actual shadows of the structures located within the image layer, the X-ray beam passes through the large area in the middle third, the lower third, and partially through the upper third of the facial structures, and even partially through the neck structures [43]. During panoramic tomography, organs with the potential for stochastic effects: the salivary glands, oral mucosa, and parts of the brain, are always located in the path of the X-ray beam. Depending on the anatomy, size, and positioning of the patient, as well as on the image-field size, the thyroid gland and the eyes may also become irradiated.

Since the introduction of the first commercially manufactured panoramic device in 1961, evolution of the technique and devices has been continuing in order to overcome technical limitations, minimize patient positioning errors, and improve image quality. Owing to digitalization of the panoramic system in the second half of the 1980s [44], many limitations have been remedied, leading to patient-dose reduction and improvement in certain diagnostic tasks [45-47]. A panoramic child program and panoramic segmented programs with several image-field restriction possibilities were provided by the devices in the beginning of the 1990s. In the new generations of panoramic devices, the image-field limitation technique restricts the X-ray beam to the area of interest, resulting in a lower patient dose than with a complete DPT. For example, paediatric orthodontic patients whose multi-phase treatment requires several DPTs may benefit from such programs.

A cephalostat is a head-positioning device for taking reproducible images of the head and facial structures either from a lateral or a posteroanterior projection. Cephalostats may be separate devices but usually they are combined within one panoramic device. During lateral cephalometric radiography, the patient's head is located between the source of radiation and the image receptor, the patient's midsagittal plane's being parallel to the image receptor. This produces a lateral view of the head and neck structures with superimposition of the structures. The central beam passes through the external auditory meatus (EAM) perpendicular to the patient's midsagittal plane and image receptor [48].

The extent of the irradiated area may range from only maxillomandibular structures to the whole cranium, facial structures, and the whole length of the cervical spine, depending on patient size, field-size, and the presence or absence of a thyroid shield [48]. Restriction of image field during lateral cephalometric radiography became possible in the end of the 1990s by use of manual collimators which limit the size of the X-ray beam. New generations of cephalostats, applied in practice from the middle of the 2000s, can reduce the size of the irradiated area in either the horizontal or vertical direction or both, simply by selecting the desired one of the preprogrammed collimation options from either a control panel or from software, prior to exposure.

2.9 Radiation-dose in panoramic tomography and cephalometric lateral radiography

DPT- and LCR devices have preprogrammed symbols or manual exposure values for patient-dose control during panoramic tomography and lateral cephalometric radiography. Exposure parameters vary depending on type of device, type of program, patient age, size, and anatomy. Usually tube voltage ranges from 57 to 90 kV, tube current from 5 to 16 mA, and the exposure time from 5 to 20 seconds during panoramic tomography and lateral cephalometric radiography. Optimization of these parameters in order to minimize patient dose but still obtain an image with sufficient diagnostic value is of utmost importance.

The range of effective dose in panoramic tomography ranges from 2.7 to 24.3 μSv, and for cephalometric radiography the dose is less than 6 μSv [29]. These dose levels are comparable to a few days' or a few hours' background radiation, considering the average annual natural background radiation dose (3,200 μSv) for the Finnish population [49]. Despite the relatively low dose levels of panoramic tomography and lateral cephalometric radiography, justification and optimization of these radiographic examinations should not be neglected, based on the following ICRP statement: "*A non-threshold relationship for stochastic effects is that some finite risk must be accepted at any level of protection. Zero risk is not an option*" [1].

DAP can be directly measured by an ionization chamber placed at the surface of the X-ray collimator. During dental panoramic radiography, the DAP value can be calculated and displayed; it depends on exposure parameters, radiation filtering, and on the collimations used, as well as on the distance between X-ray source and patient [50]. DAP value differs among DPT devices. The STUK permits a 25% deviation between displayed DAP and true DAP because of differences in measuring systems and calibration methods [51]. According to the user manual of some devices [52], a displayed DAP value of a standard panoramic program ranges from 12 to 87 mGy×cm^2, and that of a paediatric panoramic program from10 to 70 mGy×cm^2. A DAP value of maximum field-size in LCR ranges from 8 to 18 mGy×cm^2, and that of minimum field-size (maximum collimation posteriorly and superiorly) from 4 to 8 mGy×cm^2 [52].

2.10 Optimization of DPT- and LCR examinations

2.10.1 Implementation of the ALARA principle

After carrying out of the justification process for a radiological examination, the imaging procedures should be optimized. Optimizing the patient's radiation dose is a regulatory requirement and can be achieved through several methods either related to the equipment used or the performance of the exposure:

1) Exposure parameters: X-ray tube voltage (measured in kilovolts, kV) defines its level of energy. A higher tube voltage results in a lower patient skin dose but higher "depth" dose and increased scatter radiation [2, 29]. The product of tube current across X-ray tube (measured in milliamperes, mA) and exposure time (measured in seconds, s) defines the number of photons generated in the X-ray tube. Higher tube current-exposure time (measured in milliampere seconds, mAs) results in a higher patient dose [2, 29]. Selection of appropriate exposure parameters to obtain acceptable image quality is desirable and is an integral part of optimization of exposure [29].
2) Irradiated field-size and collimation: The size of the X-ray beam is associated with total energy absorbed by the patient and personnel. Reduction in the beam reduces the dose absorbed by patients [29]. The different types and forms of collimators on the path of the primary X-ray beam easily limit the beam size to the area of clinical interest. This is an easily applicable method and prevents unnecessary tissue exposure [53, 54].
3) Filtration: Filtration of the X-ray beam, using aluminium or other materials, eliminates X-ray photons with a lower energy level, and thereby reduces the patient's skin dose [2, 29].
4) Choice of image receptor: Digital radiography in which conventional screen/film combinations are replaced either with photostimulable storage phosphor image plates or with imaging sensors based on charge-coupled devices offers a considerable dose reduction to patients [2].
5) Shielding radiosensitive organs: Organ shielding has been very effective in dose reduction [2]. Shielding of organs located nearer than five centimeters from the primary beam is necessary if the shadow of the shield does not impair image quality or if it does not hamper visualization of the anatomical landmarks [19].

6) Correct patient positioning: Patient positioning errors and failure in patient immobilization may lead into decreased image quality, irradiation of unwanted organs, and an increased number of failed and repeated exposures, causing unnecessarily increased dose to the patient [2].
7) Appropriate projections: Selection of appropriate projections is an important aspect of optimization because it minimizes the dose imparted to radiosensitive organs [29].
8) Number of exposures: Reducing the total number of radiological examinations reduces both individual effective dose and overall collective effective dose [55].

2.10.2 Methods of patient-dose reduction in panoramic tomography and cephalometric radiography

Adjustment of the exposure parameter influences the patient's radiation dose, but reduction in field size is a powerful means of significant reduction in total absorbed dose. Field-size reduction does not, however, necessarily impact the equivalent dose to organs that remain in the path of the primary X-ray beam. In addition, shielding of radiosensitive organs protects them significantly against ionising radiation [2].

2.10.2.1 Field-size restriction

DPT field restriction, for example by application of a child- or segmented program, results in a lower organ dose and consequently lower patient dose when compared to an adult program. The European Commission and British Orthodontic Society recommend proper beam limitation to the area of clinical interest during panoramic tomography [2, 39] (Table 2).

LCR field-size restriction by use of different collimators, leaving organs and structures not required for cephalometric analysis out of the irradiated area, results in a lower organ-dose and consequently in a lower total patient effective dose when compared to the non-collimated situation. The European Commission and British Orthodontic Society recommend proper beam limitation to the area of clinical interest during lateral cephalometric radiography [2, 39].

Table 2 Effective dose reduction for organs, potential for stochastic effects of radiation during field-size reduction options for dental panoramic tomography.

Program type or field-size reduction	Effective organ-dose reduction (%)							Source
	Thyroid gland	Eyes	Submandibular gland	Parotid gland	Brain	Oral mucosa	Total in %	
Beam height reduction (30 mm)	21	41		11	57	4	32	Davis *et al.,* 2015 [56]
Posterior 2/5 segmented DPT							74*	Tan *et al.*, 2013 [57]
Mid 1/5 segmented DPT							77*	Tan *et al.*, 2013 [57]
Horizontal lower 2/3 segmented DPT							15*	Tan *et al.*, 2013 [57]
TMJ area collimation							20	Wahlmann *et al.,* 2012 [58]
Half panoramic							40	Wahlmann *et al.,* 2012 [58]
Dentition only							50	Isaacson *et al.,* 2008 [39]
Child program	>50	60-90	8-43*	3-34*	14-85*		45*	Hayakawa *et al.,* 2001 [59]
Beam height reduction to dentoalveolar region	70							Locht 1983 [60]

*Calculated based on values in original article or abstract.

Collimators with compensated filtration and a wedge-shaped collimator can be used to leave only structures required for orthodontic diagnosis in the path of the primary X-ray beam, leaving a large area of the cranium and cervical vertebrae out of the irradiated area. A filtration-compensated collimator is made from plastic, lead, and aluminium whereas a wedge-shaped collimator is made from lead (Table 3) [61, 62].

Table 3 Effective dose reduction for organs, potential for stochastic effects of radiation during field-size reduction options for lateral cephalometric radiography.

Collimation type and field-size reduction (FSR)	Effective organ-dose reduction (%)							Source
	Thyroid gland	Eyes	Salivary glands			Brain	Total in %	
			Sub-mandibular gland	Parotid gland	Sub-lingual gland			
Filtration compensated collimator (40% FSR)	61	33	31	11			34	Alcaraz *et al.,* 2009 [61]
Wedge-shaped (55% FSR)	29*		14*			83*	41	Gijbels *et al.,* 2003 [62]
Collimation to the face	36*							Eliasson *et al.,* 1984 [63]

*Calculated based on values in original article.

2.10.2.2 Thyroid shielding

The thyroid gland is the largest endocrine gland in the neck area. It consists of two lobes connected by the isthmus anteriorly in the midsagittal plane. The level of the upper and lower borders of the thyroid gland in relation to vertebral level varies with age, being lower in adults than in children as a result of downward migration of its buds during the developmental process and during its morphogenesis [64, 65]. In adults, the upper borders of the thyroid gland are located at the level of the fifth cervical vertebra, and the lower border at the level of the first thoracic vertebra [66]. In children, a larger compartment of neck structures becomes irradiated than in adults during lateral cephalometric radiography in the absence of a thyroid shield [65].

During lateral cephalometric radiography, it is possible to exclude the thyroid gland from the irradiated field either by shielding it or collimating it out of the X-ray beam, with the first method's being more effective in organ-dose reduction (Tables 3 and 4). A dose to the thyroid gland cannot, however, be completely avoided because of internally scattered radiation [19]. Shielding of the thyroid gland is a necessary and easily applicable method if the field collimation does not exclude the thyroid gland from the irradiated area [2]. This procedure results in both total effective dose reduction and organ-dose reduction of the thyroid gland (Table 4).

During dental panoramic tomography, as a result of the panoramic technique, and the 6- to 8-degree upward angulation of the X-ray beam, the thyroid gland may partially fall in the path of the primary X-ray beam, if the diameter of the beam is too wide in the vertical plane, or if the patient's chin position is not optimal [67]. Using a thyroid shield in DPT exposure has, however, turned out to be inappropriate because of its interference with the primary beam and its hampering the view of the symphysis area [2]. One way to reduce the amount of scattered radiation received by the thyroid gland and its equivalent dose is by maintaining the maximum distance between the thyroid gland and the primary X-ray beam [2]. This can be achieved by accurate positioning of the patient's chin and leaving the structures below the mandibular inferior border out of the primary X-ray beam.

Table 4 Thyroid gland shielding and effective dose reduction during lateral cephalometric radiography.

Shielding type	Effective dose reduction (%)		Source
	Thyroid gland	Total body	
Thyroid collar	89	42*	Hoogeveen *et al.,* 2015 [68]
Cephalographic thyroid protector (CTP)	85	37	Hoogeveen *et al.,* 2015 [68]
Thyroid shield	82*	34	Patcas *et al.,* 2013 [69]
Thyroid shield	90*		Eliasson *et al.,* 1984 [63]

*Calculated based on values in original article.

3 Aims of the present study

The purpose of this study was to discover the main indications for taking extra-oral dental radiographs and to evaluate the implementation of the first two principles of radiation protection: the principle of justification and principle of optimization, among 7- to 12-year-old Finnish children during dental panoramic tomography and lateral cephalometric radiography for further development of radiation safety and quality of radiological practice.

The specific aims were to:

1. Discover the indications for taking DPTs, segmented DPTs, and LCRs [I, IV].
2. Evaluate the adequacy of the referrals for DPTs and LCRs [I].
3. Assess the appropriateness of DPT and LCR field-size [II] and selection of area in segmented DPTs [IV].
4. Discover the frequency of failed or repeated DPTs and LCRs [I], and of segmented DPTs [IV].
5. Explore the status of interpretation of DPTs, segmented DPTs, and LCRs, and the status of cephalometric analysis of LCRs [I, IV].
6. Discover the type, location, and frequency of pathologic and developmental findings in DPTs [III].
7. Assess the influence of continuing education and training in radiation protection with regards to application of the DPT child program and segmented DPT programs [IV].

4 Materials and methods

This study was performed based on dental records, DPTs, and LCRs of 7- to 12-year-old children receiving dental services in Oral Healthcare Department of the City of Helsinki, Finland, in 2010 and 2013-2014.

4.1 Permission

Permission to conduct the study [decision number 10-3108/054 (I-III); HEL 2012-017365 T130201 (IV)] came from the Oral Healthcare Department of the City of Helsinki, Finland.

4.2 Sample size, data collection, and randomization

4.2.1 Data from 2010

Based on the population size of Helsinki in 2010 (583,350, making up 11% of the population of Finland), and the population of 7- to 12-year-olds in Helsinki in 2010 (29,410, and accounting for 8.5% of 7- to 12-year-olds in Finland), we decided to include 10% of all DPTs of 7- to 12-year-olds at the Oral Healthcare Department of the City of Helsinki. We took into account the extent and scope of dental services it offers to children. Considering the total number of DPTs of 7- to 12-year-olds in Finland (23,862), we estimated that of those, 10% would be 202 DPTs. We decided, however, to include 250 patients in the first and second [I, II] parts of the study (Figure 1). Retrospective data were collected during a 5-month period by a resident in oral radiology (E.P.E.) in 2011. From the electronic patient information system Effica® (Tieto, Helsinki, Finland) came a list including those patients of whom either a DPT or an LCR or both had been taken during 2010 at the age of 7- to 12-years at the time of the exposure, on the 5th, 15th, or 25th day of each month. This list contained the name and social security number of 394 patients, which exceeded the estimated 250 study subjects determined at the moment of sample-size calculation. Therefore, every other patient or sometimes consecutive patients from the list were chosen in order to ensure a sum of 250 (Figure 1).

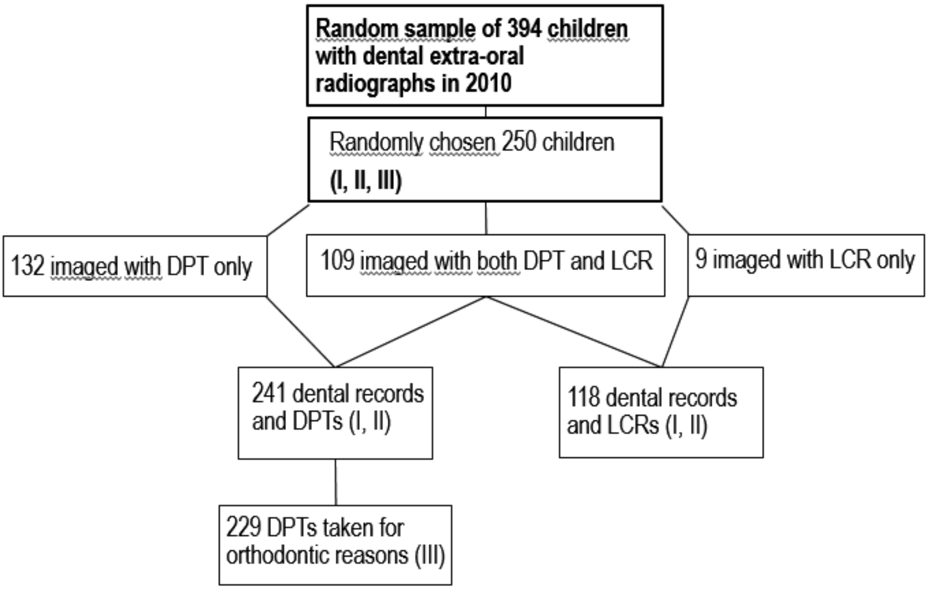

Figure 1 Study subjects from 2010 in the City of Helsinki (Studies I-III).

We included 413 patients imaged with a DPT for orthodontic reasons for our study [III]: 229 from 2010 and 184 patients from a separate series in 2013-2014 (see below).

4.2.2 Data from 2013 - 2014

The decision was to collect all DPTs taken at the Oral Healthcare Department of the City of Helsinki of 7- to 12-year-olds during one year. Prospective data were collected during a 12-month period by a specialist in oral radiology (E.P.E.) in 2013-2014. This provided a list including all the patients of whom either a DPT or segmented DPT had been taken during the study period who were aged 7 to 12 years old at the time of exposure. This list contained the name and social security number of 3,883 children (Figure 2). All DPTs were chosen and categorized in a segmented/child/adult program, and subgroups were formed for further analyses. All 76 segmented DPTs were analysed, and also 500 consecutive DPTs (using either a child or an adult program), 320 consecutive DPTs using a child program, and 200 randomly selected DPTs using an adult program (Figure 2).

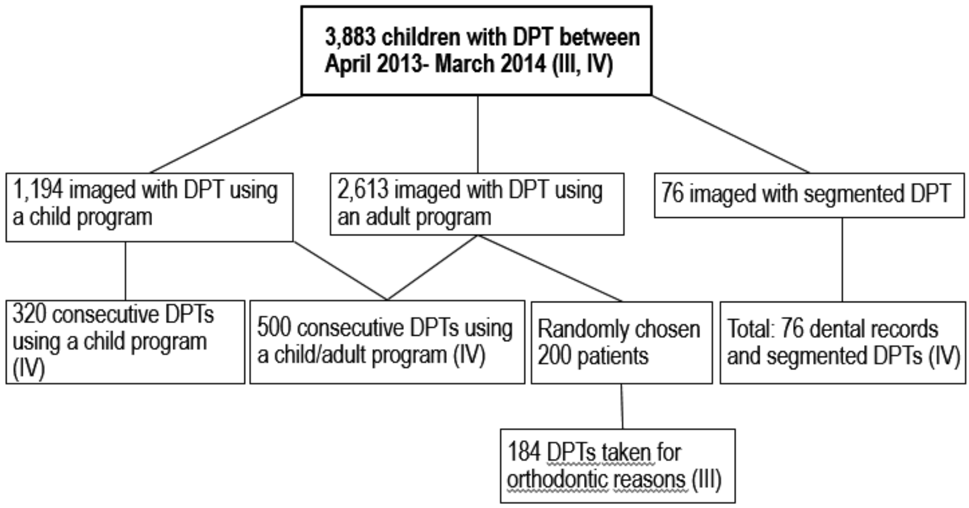

Figure 2 Study subjects from 2013-2014 in the City of Helsinki (Studies III-IV).

Randomization of the 200 patients who, in addition to those from the 2010 sample [I, II], formed the study subjects of the third study, took place as follows: from the same list of 3,883 children was selected every 20th patient with a DPT adult program, on average. From the resultant list of 200 patients, those 184 were eventually included who had been imaged for orthodontic reasons [III].

4.3 Analysis of patient files and registered information

The patients' records were analysed, and the information in Table 5 was registered anonymously by E.P.E.

4.4 Analysis of radiographs and registered information

The DPTs and LCRs were viewed with Digora® for Windows 2.5 software (Soredex Dental Malaysia, Helsinki, Finland) and high-quality Eizo MX210–FlexScan® monitors (Eizo Nanao Co, Hakusan, Ishikawa, Japan) under optimal viewing conditions without reflected light. When needed, points related to image interpretation were consulted upon with a senior oral radiologist (M.E.) and a senior orthodontist (J.W.S.). The patients' radiographs were analysed, and the information recorded was that presented in Table 6. In the fourth study, with respect to application of segmented and DPT child programs, the comparison made was between data from 2010 and from 2013-2014 [IV].

4.5 Type of DPT device

The 241 DPTs from the 2010 sample had been taken with the following devices: Orthopantomograph OP® 200 D (Instrumentarium Dental, Tuusula, Finland), Cranex® D and Cranex Excel Ceph® (Soredex, Tuusula, Finland), Orthophos XG5® (Sirona Dental System GmbH, Bensheim, Germany), and Planmeca Proline® XC (Planmeca, Helsinki, Finland) [II]. Except Planmeca Proline® XC, all of these devices had been used for taking the 500 DPTs analysed in Study IV. All the devices had several DPT programs and offered the possibility for the DPT child program and segmented DPT with different exposure parameters, taking into account patient age and size.

4.6 Intervention

A five-step intervention program took place in nine dental clinics in Helsinki that were equipped with dental panoramic devices during a 4.5-month period in 2012-2013 in order to promote the use of the DPT segmented/child program. The intervention was carried out as a part of continuing education in radiation protection and included two lectures, educational and training visits to the dental clinics, and the addition of preformulated phrases as a part of electrical referrals in the patient information system [IV].

Table 5 Information from patients' dental records (Studies I-IV).

			Registered information											
Study	**Patients**	**Patient subgroups**	**Age**	**Gender**	**Medical history**	**Radiographic indication**	**Adequacy of radiographic referral**	**Education of the referrer**	**Status of interpretation**	**Status of cephalometric analysis**	**Number of repeated exposures**	**Number and type of previous radiographs**	**Number of previous DPTs**	**DAP**
I	250 patients	241 patients with DPT	x			x	x	x	x		x	x		
		118 patients with LCR				x	x	x	x	x	x			
II	250 patients	241 patients with DPT	x											x
		118 patients with LCR												x
III	241 patients with DPT	229 patients imaged for orthodontic reasons	x	x		x								
	200 patients with DPT adult program	184 patients imaged for orthodontic reasons	x	x	x	x								
IV	76 patients with segmented DPT		x	x	x	x	x	x	x		x		x	
	320 patients with DPT child program				x						x			

Table 6 Information from patients' radiographs (Studies I-IV).

			Registered information								
Study	**Material**	**Material subgroup**	**Type of DPT program (adult/child/segmented))**	**Device specific data**	**Appropriateness of the image-field**	**Use of thyroid shield**	**Number of visible cervical vertebrae**	**General pathologic findings, developmental dental and occlusal findings**	**Caries status**	**Imaged area**	**Cropped area**
II	241 DPTs		x	x	x						
	118 LCRs				x	x	x				
III	413 DPTs taken for orthodontic reasons	229 DPTs from 2010						x			
									x		
IV	3,883 DPTs		x								
		500 DPT child/adult programs	x	x							
		320 DPT child programs									x
		76 segmented DPTs								x	

4.7 Definitions and criteria

The patient files and radiographs were evaluated based on several criteria, defined as follows:

Referral and image analysis [I]

- Adequate referral: request for radiography with mention of the indication for radiographic examination.
- Interpretation: systematic analysis of the image with a report of all findings of clinical importance, regardless of indication for radiography.
- Brief interpretation: interpretation only covering findings related to the indication for radiography but with no report of other significant observations.
- Cephalometric analysis: any cephalometric assessment.

Optimum field-size [II]

- Optimum field-size in DPT, based on anatomic criteria (Figure 3).
- Optimum field-size in LCR, based on anatomic criteria (Figure 4).

Tooth development [III]

- Acceleration in tooth development: development of a single tooth above the 90^{th} percentile of the Finnish control population [70].
- Delay in tooth development: development of a single tooth below the 10^{th} percentile of the Finnish control population [70].
- Delay or acceleration in tooth eruption: deviating more than two standard deviations from the documented mean age at eruption relevant for Finnish children [71].

Appropriate horizontal field limitation: bilateral visualization of condylar processes (A) but not visible more laterally than medio-lateral width of the EAM (B-C) on the lateral sides of the EAMs.

Appropriate vertical field limitation:
Superiorly: visualization of the condylar processes (A) but not visible more cranially than to the level of the maximum medio-lateral width of the orbits (D-E).
Inferiorly: visualization of the inferior border of the mandible (F) but not visible more inferiorly. Limit slightly below the level of the bony mandible in the symphysis area accepted as it might represent soft tissue of the chin.

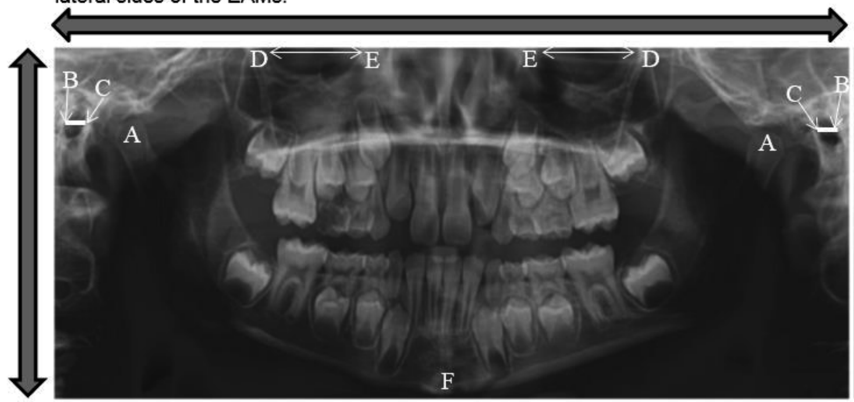

Figure 3 Criteria for optimum field-size in a dental panoramic tomograph.

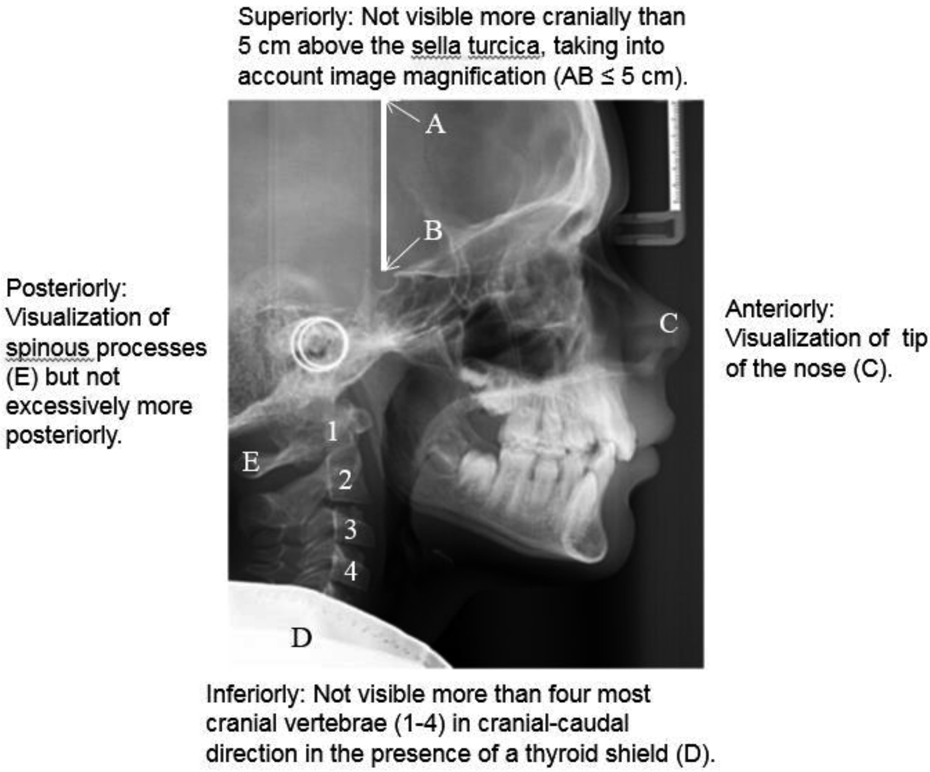

Figure 4 Criteria for optimum field-size in a lateral cephalometric radiograph.

4.8 Statistical methods

Chi Square testing with R language (version 2.13.0; R Development Core Team, R: A Language and Environment for Statistical Computing, Vienna, Austria, 2008) served to assess the significance of difference between the reasons for ordering the DPTs [I], and the significance of difference between subgroups of orthodontic reasons in both DPTs and LCRs [I].

Logistic regression analysis using R language served to determine associations between the following variables:

1. Age of the patient and:
    a. proportion of the DPTs [I]
    b. type of DPT program [II]
    c. appropriateness of field-size for both DPTs and LCRs [II]

2. Education of the referring dentist and:
    a. type of radiograph ordered (whether DPT or LCR) [I]
    b. quality of referral [I]
    c. status of interpretation of DPT [I]
    d. status of interpretation and cephalometric analysis of LCR [I]
3. Type of radiograph ordered (whether DPT or LCR) and quality of referrals [I]
4. Appropriateness of DPT field-size and:
    a. type of device [II]
    b. type of program [II]
5. Significance of increase in application of DPT child program and segmented DPT between 2010 and 2013-2014 [IV].

Cohen's Kappa was used to measure inter-observer agreement [III].

5 Results

5.1 Background data on patients and probability of radiography

The total population of this study comprised 4,133 children aged 7 to 12 years. Gender was recorded for selected subgroups. Sex distribution within subgroups was almost equal, the proportion of males ranging from 49% to 52% [III, IV].

Similarly, based on analysis of the 580 subgroups of the material, 92.5 to 94% of the patients were reported to have no general health problems [III, IV]. One patient was diagnosed with juvenile rheumatoid arthritis (JRA). The following diagnoses were recorded for the rest: asthma, general mental retardation, Down's syndrome, hypothyroidism, congenital heart disease, epilepsy, Wilms tumour, Incontinentia pigmenti, fetal leukaemia, and Von Willebrand disease, as well as attention deficit and hyperactivity disorder.

Analysis of the age-distribution in selected subgroups revealed that the probability of having DPT taken was lower in 12-year-olds than in 7-year-olds and 9- to 11-year-olds [I]. It appeared that LCRs were taken more consistently among 7- to 12-year-olds than DPTs, with no significant difference observable between different age groups [I]. Segmented DPTs were seldom taken of 7- to 8-year-olds; they were more frequently taken of 9- to 12-year-olds (Table 7).

5.2 Indications for radiography

Orthodontic reasons were the main indications for ordering dental panoramic tomography (full or segmented) and lateral cephalometric radiography [I, III, IV] (Table 8).

Of the 229 DPTs ordered for orthodontic reasons [I], 141 (62%) were taken for orthodontic patient selection, initial assessment and consultation concerning need for orthodontic therapy or observation of development of the dentition, 43 (19%) prior to initiation of orthodontic therapy, 43 (19%) during orthodontic treatment, and 2 (1%) for evaluation of the final treatment result. The difference between these subgroups was statistically significant, both regardless of age ($P < 0.0001$), and when taking age into account ($P = 0.045$).

Of the 118 LCRs [I], 51 (43%) were taken for orthodontic patient selection, initial assessment, and consultation for the need of orthodontic therapy, 48 (41%) for initiation of orthodontic therapy, 18 (15%) during orthodontic treatment, and 1 (1%) for evaluation of the final treatment result. The difference between these subgroups was statistically significant ($P < 0.001$).

Table 7 Age distribution of the 7- to 12-year-old patients (Studies I, III, IV).

Age (years)	*DPTs [I] (%)	*LCRs [I] (%)	*DPTs [III] (%)	Segmented DPTs [IV] (%)
7	41 (17)	18 (15)	59 (14)	3 (4)
8	35 (15)	20 (17)	77 (19)	4 (5)
9	50 (21)	22 (19)	100 (24)	13 (17)
10	48 (20)	20 (17)	74 (18)	22 (29)
11	45 (19)	25 (21)	67 (16)	22 (29)
12	22 (9)	13 (14)	36 (9)	12 (16)
Total	241	118	413	76

The three groups marked with an asterisk contain partly overlapping patient groups. DPT, dental panoramic tomograph; LCR, lateral cephalometric radiograph.

Table 8 Indications for DPTs and LCRs of 7- to 12-year-old patients (Studies I, III, IV).

Study	Type of radiograph	N	Orthodontic-related reasons	Non-orthodontic reasons	Unknown reasons
I	DPT	241	229 (95%)	4%	1%
	LCR	118	118 (100%)		
III	DPT	441	413 (94%)	6%	
IV	Segmented DPT	76	51 (68%)		32%

DPT, dental panoramic tomograph; LCR, lateral cephalometric radiograph.

Of the 51 segmented DPTs with known indication, 35 (69%) were taken to evaluate the presence, eruption, and localization of canines and maxillary lateral incisors. Other known indications for segmented DPTs included assessment of need for a space maintainer, initiation of orthodontic treatment, localization of supernumerary teeth, stage of eruption of permanent teeth, management of tooth autotransplantation, extraction of supernumerary teeth, and delayed eruption of premolars/molars [IV].

5.3 Educational status of referring dentist and quality of referrals

Most of the DPTs had been ordered by general dental practitioners, but most of the LCRs by orthodontists [I]. Specialists and general practitioners (GPs) were equally responsible for ordering segmented DPTs [IV] (Table 9).

Table 9 Educational status of the referring dentists (Studies I, IV).

Study	N	Type of radiograph	General practitioners	Orthodontists	Other specialists	Unknown referrer
I	241	DPT	144 (60%)	97 (40%)		
	118	LCR	42 (36%)	76 (64%)		
IV	76	Segmented DPT	37 (49%)	32 (42%)	5 (7%)	2 (2%)

DPT, dental panoramic tomograph; LCR, lateral cephalometric radiograph.

The referrals were classified as adequate for 78% (188 of 241) of the DPTs, and for 73% (86 of 118) of the LCRs [I]. The rest of the images had been ordered with inadequate referral. Orthodontists had ordered more LCRs than did GPs, and they had more often written more often inadequate referrals (Table 10).

Table 10 Associations between variables and factors (Study I).

Parameters		Age	Referrer's education
Frequency of DPTs		OR 0.50; 95 % CI 0.29-0.83	NA
Type of radiograph		NA	OR 2.68; 95 % CI 1.70-4.24
Quality of referral		NA	OR 0.44; 95% CI 0.72-0.26
Status of interpretation	DPT	NA	OR 1.29; 95 % CI 0.72-2.32
	LCR	NA	OR 3.26; 95 % CI 1.33-7.93
Status of cephalometric analysis		NA	OR 3.22; 95 % CI 1.44-7.19

DPT, dental panoramic tomograph; LCR, lateral cephalometric radiograph; OR, odds ratio; CI, confidence interval; NA: not analysed.

5.4 Radiograph analysis and interpretation

Altogether, of the 241 DPTs, 174 (72%) had been interpreted completely and 20 (8%) interpreted only briefly. Of the DPTs, 47 (20%) lacked any kind of interpretation (95% CI 14%-25%) [I].

Of the 118 LCRs, 41 (35%) had been interpreted (95% CI 0.26-0.44), and 79 (67%) had been analysed cephalometrically (95% CI 57%-75%). One-third of these LCRs (31%) (95% CI 23%-41%) lacked both interpretation and cephalometric analysis. Compared to GPs' LCRs, those LCRs ordered by orthodontists had more frequently been interpreted and more frequently cephalometrically analysed, as well (Table 10) [I].

Of the 76 segmented DPTs, 33 (43%) were interpreted completely [IV]. The proportion of interpreted segmented images was 29% smaller than that recorded for full DPTs in 2010.

5.5 Effect of intervention

Before the intervention, of the 241 patients, 187 (78%) had been imaged with a DPT adult program and the rest (22%) with a DPT child program [II]. None of the patients was imaged with segmented DPT. None of the images contained information on DAP. Selection between a DPT child program and a DPT adult program had not been performed based on patients' age (Table 11). After the intervention, 67% of the 3,883 patients had been imaged with a DPT adult program, 31% with a DPT child program, and 2% with segmented DPT [IV]. A comparison between our data from 2010 (before the intervention) and 2013-2014 (after the intervention) revealed an increase of 9% in the application of a DPT child program and 2% in the application of segmented DPT with statistical significance; OR 1.68 (95% CI 1.23-2.30, $P < 0.001$) [IV].

5.6 Appropriateness of image-field in DPTs and segmented DPTs

In the 241 images, DPT field-size was classified as appropriate horizontally in 68 (30%) (Table 11). Images taken with the Orthopantomograph OP® 200 D and the Cranex Excel Ceph® using a child program most often displayed an appropriate field-size [II].

Of these 241 images, DPT field-size was classified as appropriate vertically (inferiorly and superiorly at the same time) in 11 (4%), and either superiorly or inferiorly in 167 (31%) [II]. Only 3 (1%) of the images displayed appropriate field-size in all directions, while 109 (45%) were too far extended in all directions. DPTs of 12-year-olds more frequently showed appropriate field-size superiorly than did those taken of 7-year-olds (OR 8.76; 95% CI 2.05-37.40) (Table 11).

Table 11 Association between different variables with regards to DPT (Study II).

Parameters			**Age**	**DPT program (adult/child)**	**DPT device**
Selection of DPT program			$P = 0.35$	NA	NA
Appropriateness of image-field	Horizontal		$P = 0.2588$	$\mathbf{P < 0.0001}$	$\mathbf{P < 0.0001}$
	Vertical	Superior	$\mathbf{P = 0.01396}$	$P = 0.65$	$\mathbf{P = 0.0041}$
		Inferior	$P = 0.3932$		

DPT, dental panoramic tomograph; NA: not analysed.

Of the 320 DPTs taken using a child program, in 90 (28%) the image-field did not completely cover the TMJ area, the posterior border of the ascending rami, the crypts of the upper wisdom teeth, and roots of the unerupted upper canines. Among segmented DPTs, in a lower number of images (5%), some areas requested in the referral did not fall within the imaged area [IV].

Segmented DPTs had been taken predominantly from the anterior parts of the jaws (46%) for evaluation of the presence/absence, localization, and monitoring of the eruption and stage of development of incisors and canines [IV].

5.7 Appropriateness of image-field in LCRs and use of a thyroid shield

LCR field-size was appropriate anteriorly in all the 118 images, posteriorly in 54 (46%), superiorly in 16 (14%), and inferiorly in 28 (24%) of the images; only 17 (6%) of the LCRs displayed appropriate field-size in all directions, while 48 (41%) of the images were too extended in all directions except anteriorly.

Almost one-fourth of these images 28 (24%) displayed four cervical cranial vertebrae completely in the cranial-caudal direction. In more than half the patients (57%), the number of visible cranial vertebrae was higher, and in 19% lower [II].

Almost two-thirds of these patients, 84 (71%), had worn a thyroid shield during radiography. Of those 84 LCRs, 22 (26%) displayed fewer than four cranial vertebrae, 28 (33%) displayed four cranial vertebrae, and 34 (40%) displayed more than four. Of the total of 118 LCRs, the 24% that displayed four cranial vertebrae had all been taken in the presence of a thyroid shield [II]. The appropriateness of the LCR image-field inferiorly showed a positive correlation with patient age (Table 12).

Table 12 Association between appropriateness of LCR image-field and patient age (Study II).

Parameters			Age
Appropriateness of image-field	Posterior		*P* = 0.7741
	Vertical	Superior	*P* = 0.33761
		Inferior	***P* = 0.04078**

5.8 Repeated exposures

The radiographic examination had been repeated in a few cases for different reasons (Table 13).

Table 13 Repeated exposures, their reason and frequency (Studies I, IV).

Study	**Type of radiograph**	**Repeated exposures**	
		Frequency	**Reasons**
I	DPT	2% (6 of 241)	Patient positioning errors or moving artefacts
	LCR	3% (4 of 118)	Patient positioning errors or moving artefacts
IV	Segmented DPT	4% (3 of 76)	Excessive field reduction, segmented DPT taken by mistake instead of a full DPT
	DPT child program	0.6% (2 of 320)	Severe dimensional distortion

DPT, dental panoramic tomograph; LCR, lateral cephalometric radiograph.

5.9 Previous radiographs

Of the 241 patients with DPTs, 97 (40%) had been exposed to at least one earlier digital radiograph: 1 to 3 earlier DPTs (mean = 1.0), 1 to 2 earlier LCRs (mean = 1.0), and 1 to 7 earlier intra-oral radiographs (mean = 1.5) [I]. The approximate calculated exposed effective dose ranged from 33.7 to 101.1 µSv, based on previously reported effective doses [17] (Table 6; I).

Of the 76 patients with segmented DPT, 72 (95%) had been exposed to at least one earlier complete digital DPT, with the range being from 1 to 3 (mean = 1.4) [IV].

5.10 General pathologic, developmental dental, and occlusal findings

In 413 DPTs taken for orthodontic reasons, there existed no incidental findings in the TMJ region, or any pathologic findings in the bone structure [III].

Caries and caries-related conditions such as amputation and periapical inflammatory lesions were the most common general findings. Among developmental and occlusal findings, crowding of the dentition was the most common finding (in 50%), followed by positional anomalies and local problems with timing of eruption (in 32%), and hypodontia (in 15%) [III]. Developmental dental and occlusal findings were mostly located in the following areas: deciduous molars, permanent maxillary lateral incisors, second premolars, and permanent canines [III].

5.11 Inter-observer agreement

Inter-observer agreement on crowding and pathologic resorption was good (0.6), and on dentinal caries in deciduous teeth and positional anomalies moderate (0.5). The inter-observer agreement as to the rest of the findings (except delayed dental development, where it could not be measured because of its rarity) agreement was perfect [III].

5.12 Caries status

In the 413 DPTs taken for orthodontic reasons, dentinal caries appeared in 129 (31%), 27% showing dentinal caries of deciduous teeth (median = 2.0, range 1-6), and 16% showing dentinal caries of permanent teeth (median = 1.0, range 1 to 9) [III].

In the subsample of 184 DPTs from 2013-2014, caries and fillings in deciduous teeth were mainly distributed in the molar area. Caries distribution with regards to tooth eruption status among both deciduous and permanent teeth is in Figures 3 and 4 in Study III.

Extraction of deciduous molars because of caries was observable in 18% of 7- to 9-year-olds. Among permanent teeth, caries was predominantly observed in the first molars. Of the upper first permanent molars, 98% had erupted, and of these, 7% were decayed, and 7% were filled. Of the 364 lower first permanent molars, 99% had erupted in the oral cavity, and of these, 31 (8%) were decayed, and 37 (10%) were filled.

6 Discussion

The frequency of orthodontic treatment among children is higher than among adults, and in some populations it might reach one-third of the children between ages 11 and 14 depending on sex and socio-economic status [72, 73]. Within ages 7 to 11 years, one-third of all children are in need of early orthodontic treatment [74]. The combination of a relatively high need for orthodontic treatment among children, the association of orthodontic treatment with several DPTs and LCRs taken [75], and the high radiosensitivity of children makes it important to evaluate the justification process of dental extra-oral radiography, to optimize the exposure, and to have access to uniform instructions and protocols.

In the present study, different aspects of radiological practice were evaluated among 7- to 12-year-olds receiving orthodontic treatment or potentially receiving it in the Oral Healthcare Department of the City of Helsinki. Helsinki is the capital of Finland with a population size of 583,350 in 2010. Its Oral Healthcare offers public regional and centralized dental care services in 33 dental clinics to almost 11% of the population of Finland. It also offers orthodontic treatment to children under age 18 in their own regional dental clinics. Children in need of special dental care receive services in the university dental clinic or what is known as the unit for specialized oral care in the Helsinki Metropolitan area and Kirkkonummi.

Radiographic practice in this child population was assessed from its first step, the referral criteria, to the last step, which is the quality of interpretation that would help the clinician do clinical diagnostics and make treatment decisions. In addition, the appropriateness of field-size was analysed in DPTs and LCRs, the most common radiographic examinations among children of this age – intra-oral dental radiography excluded. The location of the most common findings of clinical interest in DPTs was recorded as a further procedure in order to evaluate possibilities for field-size reduction as an important part of dose reduction, especially during application of any segmented DPT program.

Because it emerged that children are frequently exposed to full-size DPT that utilizes adult programs with an unnecessarily large field-size, an intervention program was carried out to promote the use of segmented and DPT child programs which would be the outcome of this educational intervention.

To the best of our knowledge, no other studies evaluate the quality of radiographic examinations in paediatric dental care.

6.1 Indication

DPTs and LCRs are the most frequent radiographic examination, comprising 27% and 16% of all the conventional radiographic examinations among 7- to 12-year-olds [6], and according to the present work they were taken mainly for orthodontic reasons. Therefore, our results could be utilized in the orthodontic community. Deficiencies detected during processes of justification and optimization of the procedures can be discussed and resolved through education, professional development, and principle changes with regards to the radiation safety of children undergoing orthodontic treatment or with the potential to undergo it.

6.2 Referral

Appropriate referral criteria are essential for justifying any procedure and if widely and wisely chosen could reduce population radiation dose by around 30% [14]. Their appropriateness has rarely been studied. In one emergency department, the referral rate for radiography was appropriate (fulfilling the criteria of the Royal College of Radiologists Guidelines) for 44% of patients attending for the first time [76]. Indeed, application of referral guidelines as a marker of good clinical practice means that practitioners are more accurate concerning the necessity of any type of radiography; this reduces unnecessary exposures [77].

In the present study, one of five DPTs and one of four LCRs were ordered without an adequate referral. The reason for those radiographs we explored through time-consuming inspection of patients' files and extraction of any relevant information that might explain the reason for that radiography. Indeed, lack of an adequate referral complicates justifying a radiographic examination by the person responsible for the exposure. Discovering the reason for radiography before exposure in such cases may be very time-consuming, not cost-effective, and may even be impossible, taking into account the educational level of the radiographers or of the dental nurses qualified to perform the radiography. In small units, communication between the referring dentist and the dental nurses who perform the radiography may take place easily despite an inadequate referral, but this may be impossible in larger organizations. Adequate referral acts as a link between the referring practitioner and the person conducting the exposure and saves time for solving the actual problem. The referring dentist has an obligation to provide an adequate referral, including the patient's signs, symptoms, and history, and to explain the reason for the exposure, based upon which the dental nurse or radiographer can justify the exposure.

Both orthodontists and GPs involved in orthodontics must be aware of the importance and meaning of writing an adequate referral for radiography. It is not good practice to omit the reason for the radiography, even in cases where the reason may appear self-explanatory. Radiography without any stated reason is unjustified. Lack of proper knowledge in this field among both orthodontists and GPs may explain the deficiency noticed in the present study. Improvement can come through reminding everyone of the importance of this issue to the orthodontic community, for example by discussing this deficiency in their regular work-place meetings.

6.3 DPT program type and image-field size

This study revealed that of the majority (78%) of 7- to 12-year-olds, DPT was taken using an adult program. Moreover, 19% of the children underwent dental panoramic tomography to monitor orthodontic treatment with the existence of an initial full DPT from the beginning of the treatment phase, and yet segmented DPTs were not taken at all, despite their availability in all DPT devices.

Analysis of the appropriateness of the exposed area showed that the majority of DPTs and LCRs did not fulfil our formulated criteria based on the extent of areas of clinical interest. As exemplified by Figures 5 and 6, image-field often was too large and extended far away from the actual area of clinical interest, leading to irradiation of children's radiosensitive organs without any significance for diagnosis and treatment planning.

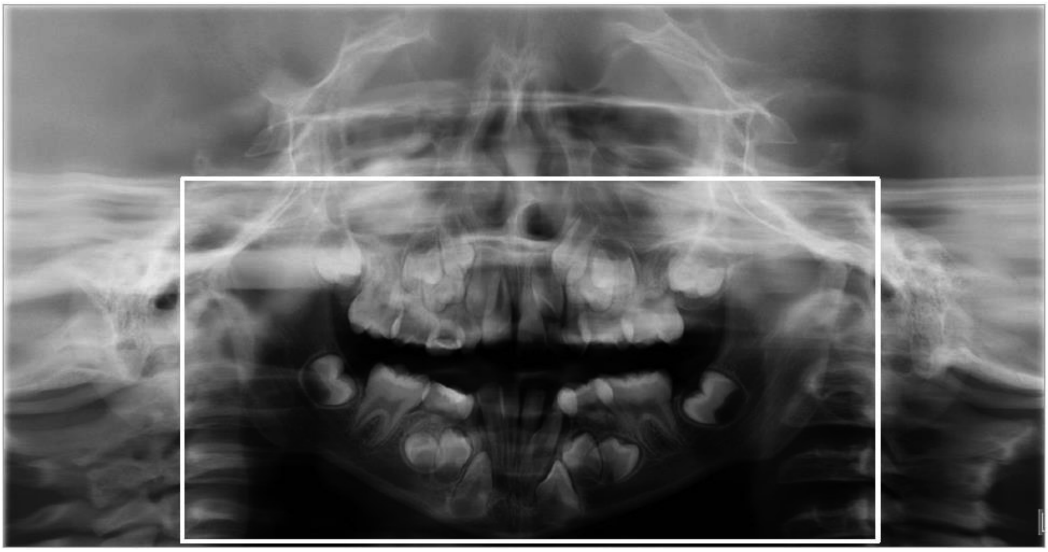

Figure 5 DPT taken with an adult program. The patient is a young child in early mixed dentition. It is evident that large areas of the upper third of facial structures have been irradiated. Bilaterally, we can visualize a much larger area than required. The area of interest is framed in white.

Figure 6 Non-collimated LCR of a child in late mixed dentition. Notably, a large area of the skull and all cervical vertebrae have been irradiated. Note the too-caudal placement of the thyroid shield (white arrow), leading to thyroid gland exposure. The area required for diagnosis and treatment planning is framed in white. Note the optimum thyroid shield placement (asterisk) with visualization of four cervical vertebrae.

What should be borne in mind is that management of orthodontic patients without craniofacial malformations does not necessarily require visualization of the whole cranium and neck area, and the image-field can be restricted to the areas presenting landmarks for cephalometric analysis, and when necessary, cervical corpora for determination of cervical vertebral maturation (CVM). Nor is imaging the whole cranium in order to detect any incidental findings justified, because most incidental findings are clinically insignificant, and their detection or exclusion has no impact on treatment [78].

Moreover, in those cases when only the inclination of incisors or labiopalatal location of canines from a lateral view is required, further restriction of the image-field to the actual area needed for patient management should be precisely considered.

To motivate acceptance of recommendations concerning image-size reduction, we analysed the location of the most important findings in DPT in children. It turned out that all the pathologic and developmental findings affecting patient diagnosis and treatment planning were located in the tooth-bearing area. No incidental finding in the area of TMJs or bony pathology was observable in the cohort studied. We could therefore conclude that, when findings related to the dentition are sufficient for patient management, DPT field restriction to the area of dentition, for example by segmented DPT, could be case-specifically considered.

Analysis of the segmented DPTs showed that their image-field size corresponded conveniently to the indication of the radiography and the area of interest, without any need for repeated exposure. In these images, only structures needed for patient management were included in the final image, thus promoting radiation safety for these children.

6.4 Growth aspects and need for image-field adjustment

Study subjects comprised children between the ages of 7 to 12 years. It can be assumed that children at each extreme of this age group could be very different in size. Individuals go through pubertal development between 9 and 15 years of age with acceleration of physical growth in height and weight [79, 80]. A 12-year-old female could be much further developed in size than a 7-year-old male. This difference in size becomes an even more important issue when we discuss all minors under age 18, although we know that the neurocranium grows relatively little after the brain has achieved its maximum size at about 8 years of age; growth in the head area is largely growth of the viscerocranium and mostly in the vertical direction [81].

At the moment, manufacturers each offer only one type of child program, one that could not possibly be suitable for children of all age groups. It also became apparent in this study that some DPT child programs also demonstrate a too-large field-size, confirming that only one type of DPT child program is insufficient for children of all age groups.

An association appeared between patient age and appropriateness of the superior aspect of DPT field-size. DPTs of 12-year-olds were more often limited appropriately superiorly than were those for other age groups. Twelve-year-olds have, as expected, a higher facial height than do younger age groups, as growth of facial structures takes place mainly in a vertical direction [82]. This leads to less exposure of the eyes, and this determines the appropriateness of the superior aspect of the image during panoramic tomography.

It also became clear that the preference for a DPT adult program over a DPT child program was not associated with patient age but with type of device. All of the DPTs taken with the Orthophos XG5® and all except one taken with the Cranex D® were taken using an adult program. What may explain the reason for such a rare application of the DPT child program with these devices could be their excessive field limitation, leading to the omission from the image-field of some anatomical structures such as TMJ and unerupted upper canines. Cutting off anatomical structures might complicate initial treatment planning, leading to repeated exposure with an adult program with higher exposure parameters and larger X-ray beam dimension, leading to a higher patient dose. Therefore, from a radiological safety point of view, there should exist several beam-limitation adjustment possibilities during dental panoramic tomography for different age groups both vertically and horizontally.

In the present work, only 6% of the LCRs fulfilled our criteria set for proper field-size in LCR. Limited possibilities for beam collimation in different planes, especially superiorly, is the explanation for this deficiency. Some devices have several beam limitation possibilities posteriorly and superiorly, whereas others have, in each direction, only one limitation possibility, or provide even fewer choices.

LCR field-size adjustment for children of different age groups might be challenging because of large growth variety. Data of the Helsinki Longitudinal Growth Study for the average horizontal and vertical growth of facial structures from age 7 to 12 were analysed to explore the need for LCR field-size adjustment in this age range. The distance from the soft-tissue tip of the nose (Pronasale) to the posterior margin of the foramen magnum (Opisthion) increased by 12 mm on average in the horizontal plane. From 7 to 12 years, the vertical change in facial size, measured as the distance between Glabella and Menton increased by 6 mm on average in the vertical plane. This measurement revealed larger growth in the horizontal plane than in the vertical plane in this age group, probably because of inclusion of the soft-tissue tip of the nose in the measurement. Naturally, a much larger increase in facial dimension is anticipated concerning the whole range of ages in the orthodontic population.

These kinds of measures should be utilized when manufacturers design new LCR devices with different collimation possibilities in different planes for patients of different cranial sizes. Designing new devices for individualized extra-oral radiography, ones capable of determining the size of the area needing to be imaged and further with adjustment of field-size, is desirable and would promote optimization processes significantly. Availability of dose-reduction measures during the purchase of new devices for imaging children is emphasized by the ICRP as well [19].

Traditional horizontal and vertical collimators may not be enough to exclude the brain completely from the irradiated area without interfering with some landmarks required for cephalometric analysis. A recently invented anatomical cranial collimator (ACC) used during lateral cephalometric radiography has reduced the irradiated area by 27 to 35% by shielding part of the skull without significant interference with cephalometric landmarks [68, 83]. Combining an ACC with a cephalographic thyroid protector (CTP) leads to 59% dose reduction [68].

According to statistics maintained by the STUK, based on its inspections, more than 90% of the panoramic devices and cephalostats in Finland came from the manufacturers of the devices studied here. These devices are used worldwide, as well. For this reason, deficiencies noticed in this work with respect to field limitation options may apply globally.

6.5 Thyroid protection and assessment of cervical vertebrae

Similar to other stochastic effects, no universal threshold exists for development of radiation-induced thyroid cancer [84]. The linear non-threshold theory (LNT) calculates the possibility of cancer risk during exposure at low doses of radiation [14]. Based on the LNT, a mean dose of 0.90 mGy absorbed by the thyroid gland of paediatric patients during computed tomography of the cervical spine elevates the lifetime risk for development of thyroid cancer between 13 and 25% [85]. There exist studies attempting to find the lowest level of radiation that might cause increased incidence of thyroid cancer [86-89]. An association exists between cumulative radiation dose to the thyroid gland and risk for developing thyroid cancer [87, 89], and an association between multiple exposures to dental X-rays and increased risk for the same cancer [88]. During medical and dental X-ray examinations, a dose more than 0.59 mGy imparted to the thyroid gland might be associated with increased risk for papillary thyroid cancer [86]. An increased risk for developing thyroid cancer has been observable among individuals whose thyroid gland has received between 20 and 39.9 Gy radiation dose during radiotherapy [89]. Indeed, in addition to the radiation dose received by the thyroid gland, other factors such as age, gender, and lifestyle in different populations affect the incidence of radiation-induced thyroid cancer [86, 89, 90].

The present study revealed that placement of the thyroid shield on the patients' neck does not guarantee protection of the thyroid gland from the irradiated area. In the study of Hujoel *et al.,* (2006), a thyroid shield was present in 19% of the LCRs [65]. In our work, a thyroid shield was present in a much higher percentage of LCRs (71%).

Considering all the LCRs, more than four cranial cervical vertebrae were visible in 57% of our images; in the presence of a thyroid shield, more than four were visible in 29%, and in the absence of the thyroid shield, more than four were visible in 28%. Four cranial cervical vertebrae were visible in 24% of the images, and all these had been taken with a thyroid shield present.

Despite recommendations for application of a thyroid shield during lateral cephalometric radiography [2], the infrequent use of the thyroid shield [65] and placing the thyroid shield at the wrong level are very concerning issues owing to the high radiosensitivity of a child's thyroid gland. Guidelines for orthodontic radiography provide no recommendation with regards to application of the thyroid shield. Shielding radiosensitive organs should not, however, limit necessary diagnostic information or affect landmark identification [19]. Management of orthodontic patients requires cephalometric analysis and sometimes determination of cervical vertebral maturation (CVM) requiring identification of C2-C4, as well [91]. Identification of C2, C3, and the hyoid bone failed in one single study of LCRs taken with a thyroid shield present [92]. It can be assumed that fear of excessive coverage of the cervical vertebrae, jeopardizing CVM determination, as well as lack of uniform international recommendations for use of the thyroid shield could explain its disuse during lateral cephalometric radiography. An attempt to find a safe way to visualize C1-C4 in children while the thyroid gland is shielded has produced the desired result in only 68% of the study subjects, because of difficulties during placement of the shield on children's relative short necks and because of lateral ascending parts of the thyroid shield [93]. A new shielding method by use of CTP reportedly protects the thyroid gland without interfering with the cervical vertebrae area [68].

To sum up, we must have uniform instructions for use of the thyroid shield during lateral cephalometric radiography, and dental nurses or radiographers need further education and training in placement of this shield at the proper level.

6.6 Previous and repeated exposures

In the first patient sample from 2010, 40% of the 7- to 12-year-olds had had previous digital radiographs, whereas of those who underwent segmented dental panoramic tomography, 95% had undergone digital DPTs. The frequency of previous DPTs taken prior the segmented DPTs in 2013-2014 was, as expected, higher than for those taken prior to DPTs in 2010. The explanation may be that

62% of the DPTs ordered for orthodontic reasons in 2010 were taken at the beginning of treatment or for orthodontic patient selection prior to initiation of treatment, whereas segmented DPTs were mostly ordered in the middle of treatment, meaning that the patients already had had a full DPT.

In the present study, the mean number of previous DPTs and previous LCRs is low compared to the reported number of radiographs taken during at least one year of orthodontic treatment in the United States [75]. This indicates that during orthodontic treatment children are imaged at longer intervals in Finland than in some other countries. The concept of proper indication for orthodontic radiography may also have changed during the past decade.

The prevalence of repeated exposures for all DPT categories and for LCRs remained under the 10% level of unacceptable radiographs permitted by the European Commission but slightly exceeded 1%, which, with a range of 0.5 to 2% depending on type of examination, is the proportion of unacceptable radiographs permitted by the STUK. After the educational intervention, we observed a 9% increase in application of the DPT child program. Despite excessive field limitation, resulting in cutting off TMJ structures and mandibular rami in 28% of the DPTs, the number of repeated exposures did not rise - in fact we noticed a decrease of 1.4% (2% to 0.6%). Patients underwent repeated radiography not because of excessive field limitation, but because of dimensional distortion of the radiographs.

According to the instructions of the STUK [28], all new devices must be equipped with the DAP display system. DPTs and LCRs in our project were, however, taken with devices purchased before introduction of these instructions. For this reason, no information exists on the DAP value of our images.

6.7 Image analysis and interpretation

In line with the standards of good practice, all radiographs must be systematically reviewed and analysed to gain maximum benefit from the examination for diagnostics and treatment. And clinical information relevant to the interpretation should be mentioned in the referral [23, 94].

Radiographic interpretation must be accurate and wide, reporting all critical abnormal findings, both anticipated and unanticipated. Reporting only those observations relevant to the specific clinical question is unsatisfactory. The whole image must be assessed and all unexpected findings reported. Furthermore, the conclusion from the main findings should appear at the end of the interpretation [94].

In this work, image reporting was unsatisfactory, as one-fifth of the DPTs and almost two-thirds of the LCRs lacked any interpretation. The higher frequency of image reporting for DPTs than for LCRs, and the higher frequency of cephalometric analysis of LCRs than for their interpretation probably arises from the incorrect belief that lateral cephalometric radiographs should only be analysed for reporting the dental and skeletal relationship.

What must be kept in mind is that during lateral cephalometric radiography, the technical difference between an LCR and a lateral skull projection is in the standardized head orientation and its reproducibility for each patient. Indeed, different types of collimators might limit the image area in

LCR, and aluminium filters are used for visualization of soft tissues. In line with good practice, each LCR, in addition to cephalometric landmark identification, must be evaluated through a methodological approach for examining radiographic images corresponding to image-field coverage [94]. Special attention should focus on the following issues during visual exploration of an LCR: disruption of the normal anatomy, integrity and size of the hypophysial fossa/sella turcica, radiodensity of mastoid air cells and the paranasal sinuses, assessment of the vessel grooves, structure and diplopic space, intracranial calcifications, the upper airway, position of the soft palate, nasopharynx, oropharynx, hypopharynx, and dorsum of the tongue, as well as general alignment of the vertebrae.

In the case of any head injury, skull fractures and foreign bodies must be sought and be excluded [48, 95]. If identification of the cephalometric landmarks alone is enough for patient management, or if knowledge of the professional involved is insufficient for interpretation of the potential pathological findings in the posterior cranium and the whole cervical vertebrae, then the image-field should be limited only to the area required for cephalometric analysis. In cases where the whole cranium and cervical vertebrae are located in the image-field, in the absence of proper knowledge, identification of pathology may fail unless a general radiologist is consulted.

LCR interpretation and cephalometric analysis were most frequently performed when the referring dentist was an orthodontist. The lower frequency of adequate referrals for LCR but higher frequency of their analysis by orthodontists than by GPs is intriguing. One explanation may be that orthodontists may perceive the indication for LCR as self-explanatory, whereas they need the analysis for diagnosis and treatment planning, and their education makes them capable of providing image reports and analyses.

After our educational intervention, segmented DPTs were initiated, but unfortunately more than half the segmented DPTs lacked interpretation. A possible explanation for this deficiency is the incorrect belief that segmented images do not require interpretation because of their smaller field-size and less coverage of the teeth compared to a full DPT and the very specific question for which they serve, such as position of a canine. Yet, each image, whatever its size and indication, should be properly analysed and interpreted.

6.8 Radiographic findings and their location

For an estimate of the value of DPTs in this age group of 7 to 12 years, we sought, in these children's radiographs, the types and frequencies of pathologic and developmental findings. Special attention was also paid to the location of those findings to make it possible to focus the irradiated field-size on the area of clinical interest case-specifically, when patient management does not require a full DPT.

Crowding of teeth was observable in half the DPTs, a frequency equal to that in the literature [96]. Crowding is observable clinically, but detection of factors possibly influencing dental arch-crowding may require panoramic radiography [97].

The prevalence of malocclusion among populations varies. Malocclusion, taking into account all morphological abnormalities regardless of severity, occurs in as high as 84% of children aged 7 to 15

[98], and 90% of children aged 7 to 11 [99]. Here, positional anomalies and local problems with the timing of tooth eruption were radiologically detected in one-third of study subjects. These were the most frequent occlusal findings, crowding excluded. The prevalence of malocclusion in Finnish children exposed to DPT is undoubtedly much higher, because skeletal discrepancies receive a high priority in Finnish orthodontic patient selection as compared to crowding and other dental problems that are undetectable in DPTs.

Hypodontia was observable in 15% of our patients. The prevalence of hypodontia in permanent teeth, third molars excluded, has been reported to range from 0.15 to16.2% [100]. The explanation for our higher prevalence of hypodontia than the earlier 8% in Finnish children [101] is the orthodontic nature of the present sample. As for hyperodontia, it was observable in 2% of our patients, in the range of the prevalence of hyperodontia (0.8-3%) provided by a comprehensive literature search [102].

A relationship has emerged between caries and malocclusion in the mixed dentition [103, 104]. On the other hand, fixed orthodontic appliances have been categorized as caries high-risk factors [2]. This highlights the importance of systematic evaluation of the image and reporting all findings of clinical significance, caries included.

The importance of radiological findings' having any impact on orthodontic treatment strategy is another issue. Studies indicate a negligible role for radiological findings in orthodontic diagnosis and treatment-planning decisions [105-107], and studies support the superior role of clinical examination supplemented with study models and photographs for orthodontic treatment planning [108].

In the present study, DPT findings, however, mostly comprised those that could prove necessary for orthodontic patient management, especially in the mixed dentition, as presented in *Guidelines of Orthodontic Radiographs* [39]. Radiologically detectable developmental findings such as malposition, hypodontia, and hyperodontia were frequently observable in the mixed dentition, and detection of these findings is necessary for planning orthodontic treatment. In order to manage restorative treatment and preventive measures, clinical and radiological detection of caries should occur before initiation of orthodontic treatment, because orthodontic appliances promote development of cariogenic microflora and thus a risk for new carious lesions [109, 110].

In the radiographs analysed, all the findings were located in the region of dentition, and 91% of the findings were mesial to the first permanent molars. No incidental findings were in the TMJ area or showed any pathology in the bone structure.

Carious lesions were predominantly detectable in deciduous molars and first permanent molars. The present series, showed a high prevalence of caries (27% among deciduous teeth and 16% among permanent teeth), even though 95% of the patients were imaged for orthodontic reasons. The highest prevalence of any abnormality such as hypodontia was detectable in the region of the maxillary lateral incisors, followed by the region of the mandibular second premolars and maxillary left second premolar, where hypodontia and other types of abnormalities usually occur [101, 111].

6.9 Imaging of the temporomandibular joint

The vast majority of patients in our study had been imaged for orthodontic-related reasons. Studies performed on Finnish children have found associations between Angle class II molar relationship, activator treatment, different orthodontic treatment modalities, and condylar changes based on DPT findings [112, 113]. Other studies, however, rule out any causative role for malocclusion and orthodontic treatment in TMD development [114]. One literature review on the relationship between TMD and orthodontic treatment finds a lack of evidence of orthodontic treatment's elevating the risk for development of signs and symptoms of TMD [115].

Masticatory muscle disorders and internal disorders, such as disk displacement, hypomobility, and hypermobility disorders, are mostly due to soft-tissue problems. Their management does not necessarily require radiography, and if required, conventional methods may lack any value [39]. According to the "*Guidelines on acquired temporomandibular disorder in infants, children and adolescents*" TMJ imaging is recommendable in the presence of the following: history of trauma, facial asymmetry, hard-tissue grinding or crepitus, and failure to respond to conservative TMD treatment [116, 117].

DPT as an initial screening method is well appreciated, if the patient is positioned correctly, because it enables comparison of both condylar heads. What must be kept in mind, however, is that a DPT provides a distorted view of TMJ structures laterally, with superimposition of skull-base structures [118]. Indeed, gross condylar-head deformity as a result of degenerative and inflammatory processes can be well recognized from a DPT, but visualization of early osseous abnormality and evaluation of joint space, when clinically indicated as impacting treatment strategy, requires CBCT imaging that provides more diagnostic accuracy [29]. The gold standard imaging method for evaluation of TMJ soft tissue is magnetic resonance imaging (MRI), when clinically indicated [119].

Juvenile rheumatoid arthritis (JRA), congenital and developmental anomalies of the TMJ, and unilateral condylar hyperplasia are rare conditions in children, and their management requires multiprofessional teamwork between different specialists. Several clinical signs and symptoms related to these situations and their radiological management require sophisticated imaging modalities such as CBCT and MRI. In these situations, inclusion of the entire condylar head in comparison to its partial collimation in the initial screening DPT would hardly be decisive for the diagnosis [119-121].

Of the subjects of the present study, only one was diagnosed with JRA, none was reported to suffer from TMDs, and no incidental findings emerged in the TMJ area. Furthermore, none of the patients underwent repeated DPT because of partial or total collimation of TMJ structures during application of the DPT child program.

Areas for improvement of DPT child-program design, as discussed, clearly exist, but the point is that missing part of the TMJ structures on a DPT that is not a gold standard radiographic method for TMJ imaging should not be a huge barrier against application of a child program.

6.10 Need for and timing of radiography during orthodontic treatment

Guidelines of Orthodontic Radiographs of the *British Orthodontic Society* [39] discuss the common indications for taking DPT and LCR prior to orthodontic treatment or during it. According to these guidelines, routine pre-treatment radiography of children is not justified; the individual need of each patient determines the necessity for radiography during various phases of treatment. The results of the present study indicate that Finnish orthodontic patients do not undergo radiography routinely during each treatment phase, since fewer than one-fifth of the DPTs and LCRs were ordered for monitoring orthodontic treatment. Only a few radiographs were taken at the end of the orthodontic treatment, and this confirms the lack of a routine schedule for radiographs. The majority of DPTs and almost half the LCRs were, however, taken mainly for orthodontic patient selection prior to the start of actual treatment. These were most probably used later at the start of active treatment, because only one-fifth of the DPTs were taken for the initiation of orthodontic treatment.

DPTs were more often ordered by GPs, but LCRs more often by orthodontists. This is not surprising, because most patients selected for orthodontic treatment are referred to an orthodontist via GPs, and these patients undergo dental panoramic tomography in the selection phase, whereas an LCR is usually ordered at the phase when the orthodontist has become convinced of its need at the beginning of active treatment. The routine ordering of DPT for orthodontic patient selection prior to referring the child to an orthodontist is not, however, acceptable practice; this is usually done to save the patient an additional visit and to save the time of the orthodontist. In the present work, less than half the patients underwent both DPT and LCR at the same time, indicating non-routine ordering of LCR for each orthodontic patient, which is an acceptable practice.

Our study subjects were in mixed dental developmental stages. The proportion of radiographs was almost equal between those in the stages of early and late mixed dentition, with a significantly lower prevalence for 12-year-olds. Although most children undergo orthodontic treatment in the stage of late mixed dentition [2], in Finland the tendency is for early orthodontic treatment [122], which explains the almost equal prevalence of radiographs between patients in the two dental development stages.

6.11 Intervention and change in practice

All member states of the European Union have regulations regarding continuing education in radiation safety for medical professionals. Continuing education and training after qualification is obligatory also for dental staff (European Commission, radiation protection no. 175). In Finland, all dental practitioners and dental care professionals engaged with ionising radiation are obligated to update their knowledge regarding the radiation safety of the staff and patients for a total of 20 hours of continuing education and training in radiation protection during a five-year period [123, 124]. The positive effect of continuing education and courses in radiation protection, and its necessity among dental staff with respect to the patient's maxillofacial-area radiation-dose reduction is established in the literature [125-128].

Reminding dentists of the radiation safety of children by scheduling regular updating courses and meetings is very recommendable. The present observations on the frequent use of a DPT adult program and the rarity of DPTs demonstrating appropriate field-size in all planes (1%) among children were concerning issues in children's radiation protection and encouraged us to seek a solution.

The decision was to carry out an educational intervention program, including continuing education in radiation protection of children for the entire dental staff. This led to a satisfactory, yet not ideal, result: we succeeded in reducing the application of a DPT adult program by 11% and at the same time inspired the application of a new method, the segmented DPT, applied by 2%. The prevalence of segmented DPTs, however, could have been at least 4% higher, based on the referrals (indication and area of interest) written for 67% of the 320 DPTs taken using a child program. This difference was statistically significant. To the best of our knowledge, no other interventional studies focus on improvement of optimization of children's extra-oral radiography. Despite changes in practice as a result of staff education, the DPT adult program still remained the predominant method, being used in 67% of the DPTs of 7- to 12-year-olds. This is a very concerning issue that manufacturers also should be aware of. Indeed, changing a practice that has been acceptable over the long term is very challenging and needs time.

6.12 Role of various professionals and communication aspects

The present investigation revealed that children who undergo extra-oral radiography are, with few exceptions, imaged for orthodontic-related reasons. Therefore, the specialists in children's extra-oral radiography are orthodontists, GPs involved in orthodontics, other GPs, dental nurses qualified for radiography, and oral radiologists. Specialists in various fields may be involved in the whole radiography process from the first step (assessment of necessity of for radiography) to the last (clinical decision based on radiographic interpretation). All these persons are cornerstones in respect to ensuring high-level radiation protection of children. This cannot be achieved, however, without proper knowledge and communication among them.

Communication between staff members involved in children's radiography should be fluent and free of misunderstanding. Referring practitioners must follow precisely the internationally set and nationally accepted patient selection criteria, justify the exposure in the referral, and clarify the desired program type or other collimation possibilities in the referral so that dental nurses can perform the exposure optimally according to instructions. Dental nurses should handle their equipment optimally and know the general principles associated with high-quality imaging performance, such as patient immobilization, accurate collimation to the required area, and shielding, in order to optimize the procedure and avoid repeated exposures [129]. Uniform instructions for optimizing children's extra-oral radiography should exist and be informative on how to take into account each patient's individual differences and the different types of equipment.

7 Conclusions and recommendations

The following specific conclusions can be drawn:

1. Not only the LCRs but also the vast majority of DPTs (95%) and the majority of segmented DPTs (68%) were taken for orthodontic or orthodontic-related reasons at ages 7 to 12 years.
2. Referrals for DPT and LCRs were often inadequate (22% for DPT and 27% for LCR). Orthodontists more often than GPs were found to be responsible for inadequate referrals.
3. Most of the DPTs and LCRs showed a too-large field-size both vertically and horizontally. Segmented DPTs were taken predominantly from the anterior parts of the dentition.
4. The number of failed and repeated radiographs was comparatively low (2.4%), below the level allowed by the European Commission (10%) but slightly above the level allowed by the STUK (0.5-2%).
5. Most of the DPTs had been interpreted and most of the LCRs had been cephalometrically analysed (72% of DPTs and 67% of LCRs). Notably, however, LCRs and segmented DPTs frequently lacked interpretation (65% of LCRs and 57% of segmented DPTs).
6. The DPTs of this age group displayed numerous dental, occlusal, and developmental findings in the area of dentition. Incidental findings in the area of the TMJ and pathological findings in the bone structure appeared to be extremely rare, since none of them were observable in any of the 413 full DPTs analysed.
7. Continuing education and training in radiation protection had a positive impact on radiological practice, as shown here by the increase in the application of child and segmented DPT programs after educational intervention.

The present study evaluated the whole process of extra-oral radiography and the quality of radiological practice among 7- to 12-year-olds under orthodontic treatment or the potential for it. It compared the Finnish practice to the recommendations of international guidelines in radiation protection. The value of this study is in finding areas for improvement with respect to justification and optimization of exposure during dental panoramic tomography and lateral cephalometric radiography of children, who are especially sensitive to ionising radiation. This new knowledge can be utilized broadly in paediatric dentistry and in the orthodontic community. It offers tools for radiological self-assessment processes, and supports a plan of action and continuing theoretical and practical education of the whole dental team. The significance of the study is, among this age group in dentistry, in its rarity with regards to quality assessment of radiological practice.

Areas of improvement include the referral process, image interpretation, to a notable extent proper program selection, image-field reduction procedures, and thyroid gland shielding. The number of repeated exposures, on the other hand, was relatively low, at an acceptable level. The intervention program raised the level of knowledge of the whole dental staff with respect to the optimization process, and resulted in improved practice. This kind of study can promote radiation safety for children by focusing on the ways to overcome deficiencies in practice, for example, by arranging regular work-place meetings, theoretical and practical courses and work-shops, and encouraging staff to undertake continuous professional education. In the present study, the intervention program focused on the proper DPT program (segmented/child) selection because of the markedly frequent use of a DPT adult program among children. Indeed, in the future, our recommendation is for intervention programs focusing not only on the optimization process but on all aspects of radiological practice, including referral criteria and image interpretation.

Systematic evaluation of radiological practice, especially among children, is necessary when approaching good practice and that is what we tried to carry out. Altering a practice in a better direction is challenging, expensive, time-consuming, and requires evidence-based data. Comparing the local practice to the international standards, tight communication between professionals and device manufacturers, and continuous updating of knowledge and professional skills are essential. Especially the manufacturers are in a key position for designing new machines and new programs with better collimation and adjustment settings. Informing the staff of new technical possibilities is essential, as well. Devices examined in this study are used broadly, and the results of this investigation can be beneficial to a larger population both nationally and internationally.

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